



Quiet, Efficient Fans for Spaceflight Workshop
Ohio Aerospace Institute
April 2-4, 2008

Review of Aircraft Engine Fan Noise Reduction

Dale Van Zante

Aircraft turbofan engines incorporate multiple technologies to enhance performance and durability while reducing noise emissions. Both careful aerodynamic design of the fan and proper installation of the fan into the system are requirements for achieving the performance and acoustic objectives. The design and installation characteristics of high performance aircraft engine fans will be discussed along with some 'lessons learned' that may be applicable to spaceflight fan applications.



Review of Aircraft Engine Fan Noise Reduction

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Objective: to determine if aircraft engine design and analysis techniques for performance and low noise are applicable to cooling fans

Designed for:
Efficiency
Durability
...



Designed for:
Low cost
Low cost
reliability
...



Topics

1. Fan Installation: “Why doesn’t my fan perform like the catalog says?”
2. Fan Aerodynamic Performance: “Can we do better?”
3. A ‘NASA Fan’ Test Case: A possible ‘open source’ method to advance the technology.

Fan performance is highly influenced by installation. The benefits of a high performance fan can be completely negated by ‘bad’ installation in a system.



Isn't a fan just like a battery?

Yes, in a global sense: battery moves electrons, fan moves air
BUT, the analogy fails when considering the details of how the devices will perform when installed.



V → RPM
I → Flow
R → Pressure



Governing equations:

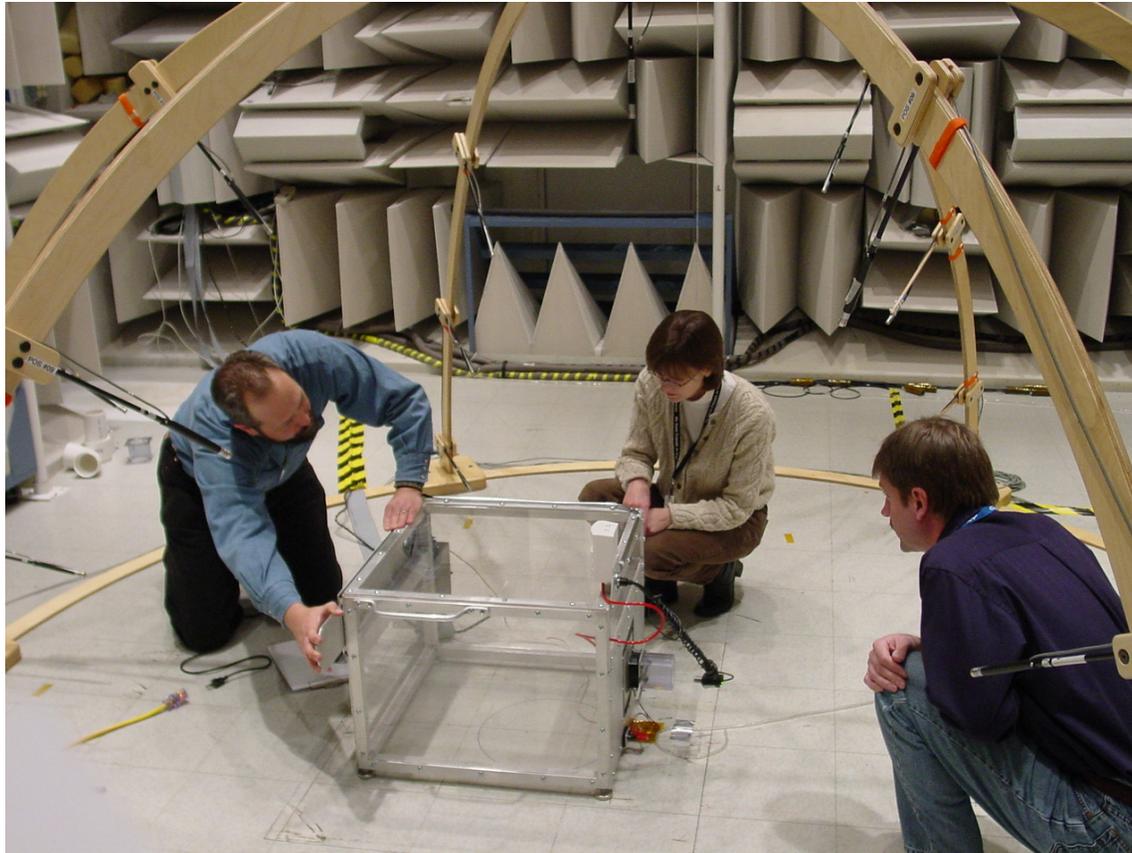
Ohm's law:
 $R = V/I$

Pressure = f(RPM, Flow, Re, inlet conditions, exit conditions, tip clearance, ...)

“ a turbomachine transfers work to a fluid through a rotating shaft primarily by fluid dynamic lift”

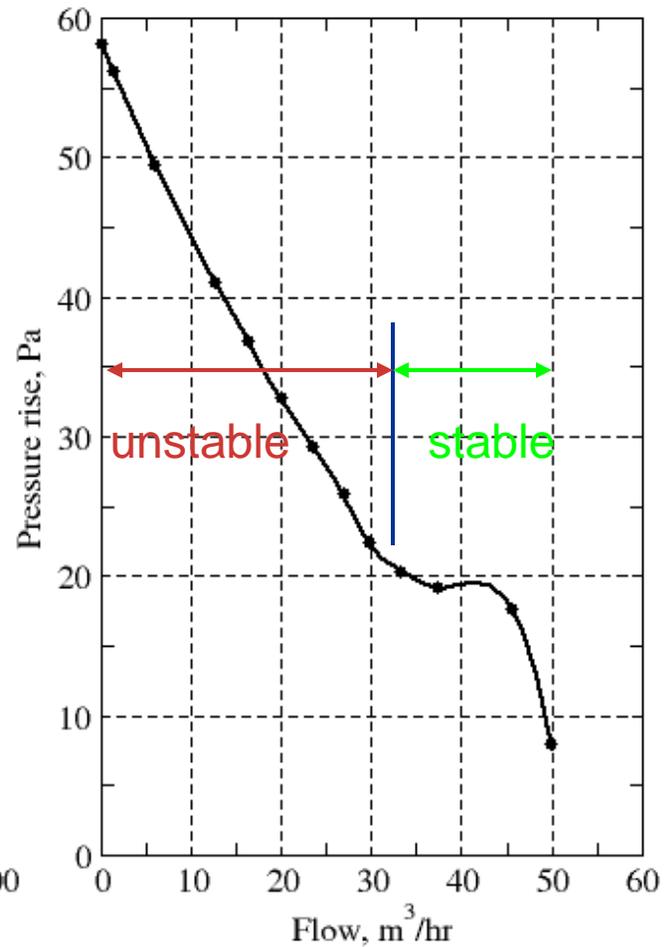
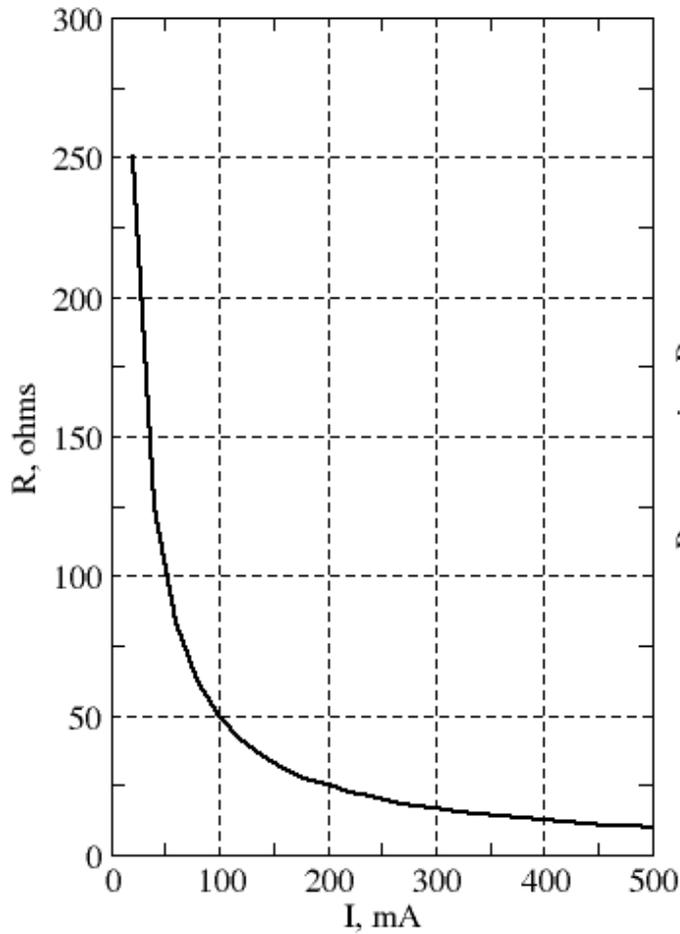


Fan Testing in ATL





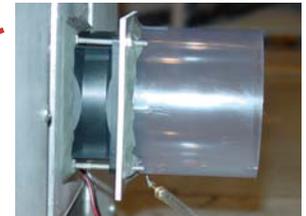
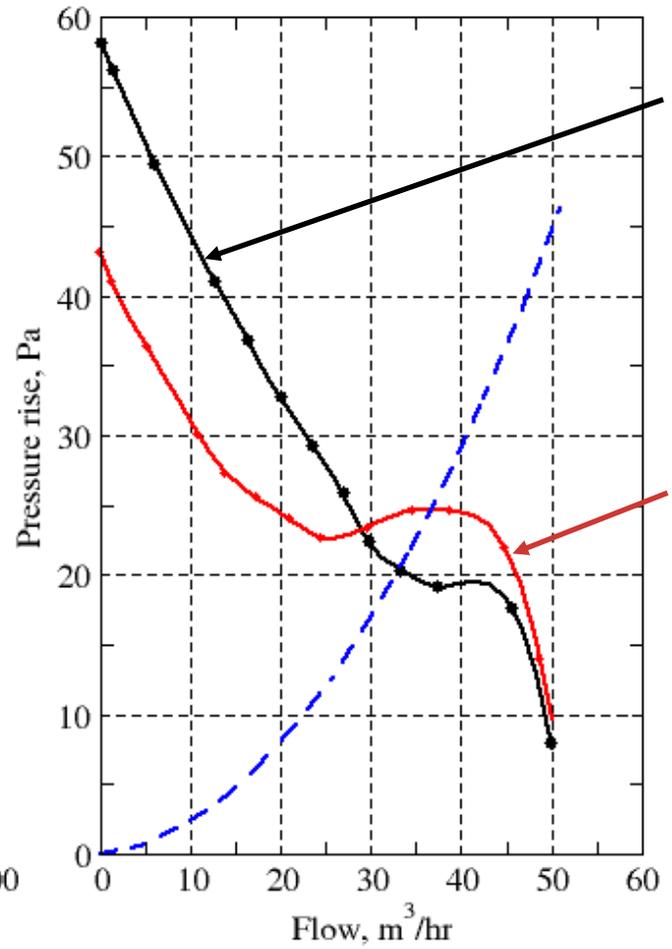
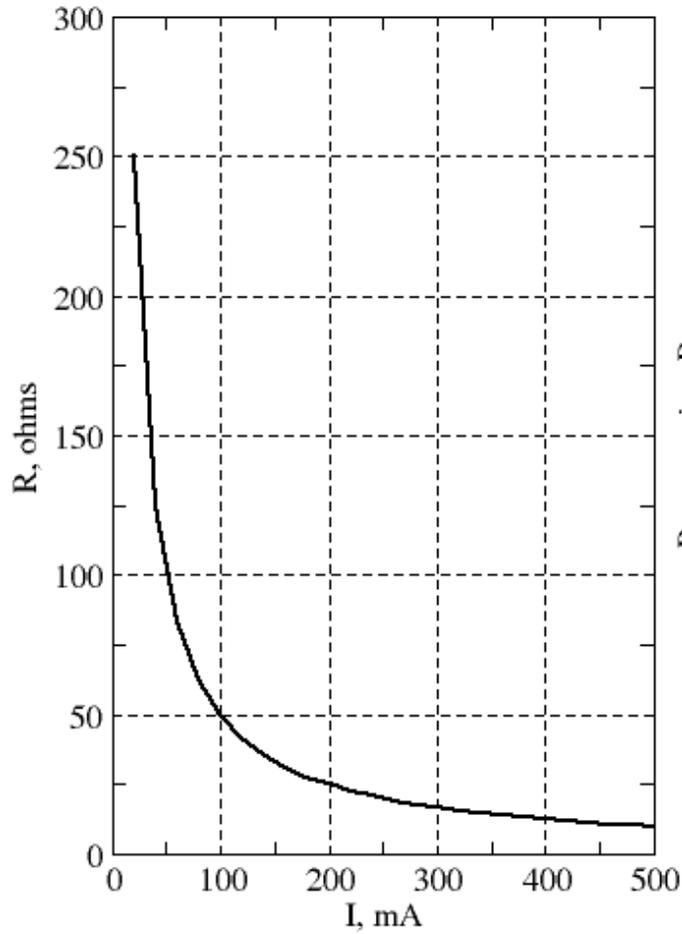
Why doesn't my fan perform like the catalog says?



The fan has a more complex operating characteristic and a limited stable range.



Why doesn't my fan perform like the catalog says?



The fan is sensitive to its inlet condition.



Why doesn't my fan perform like the catalog says?

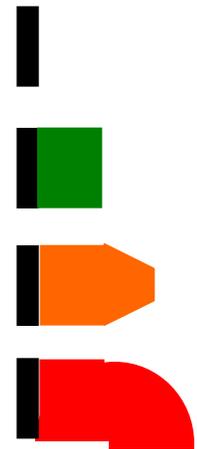
Pressure Coef.

$$\frac{P}{\rho N^2 D^2}$$

Flow Coef.

$$\frac{Q}{ND^3}$$

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Source: Nelson, David, "Axial fan installation effects due to inlet flow distortions,"
Internoise 2006, Honolulu, HI, Paper in06_381.



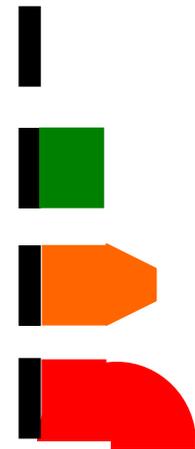
Why doesn't my fan perform like the catalog says?

Overall A-weighted
Sound Power
KwA

Flow Coef.

$$\frac{Q}{ND^3}$$

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Source: Nelson, David, "Axial fan installation effects due to inlet flow distortions,"
Internoise 2006, Honolulu, HI, Paper in06_381.



Aeroperformance: Can we do better?



Large rotor/vane spacing

P&W 4000

Aircraft engine fan design features for low noise and high efficiency.

Blade counts chosen for BPF cutoff

Swept stators

Efficient, axi-symmetric inlet with acoustic liners

Tight tip clearance

of fan blades is proper for the pressure rise

Small, contoured hub/spinner

GP7000



24 CFM @ 0.08 in. H₂O



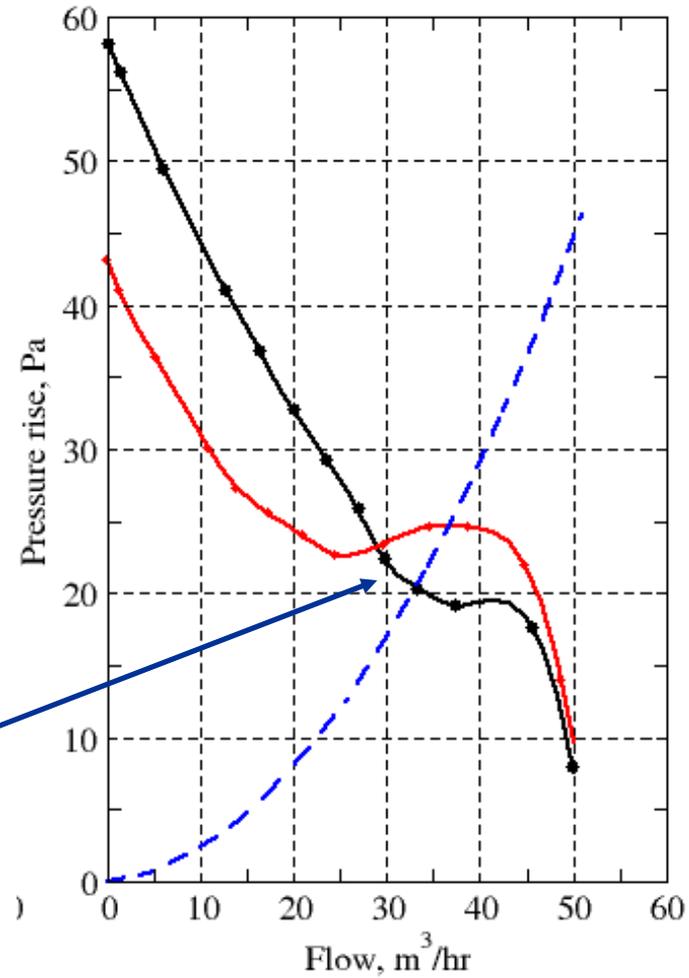
The cooling fan shows many less than optimum design features.

	Cooling Fan	Aircraft Fan Model
Casing radius	38 mm	279.4 mm
Tip radius	37 mm	278.9 mm
Hub radius	26 mm	83.8 mm
Hub/Tip ratio	0.70	0.30
Operating speed	3,300 rpm	12, 657 rpm
Tip speed	12.8 m/s	370 m/s
Clr height	1 mm	0.5 mm
Blade chord	34 mm	94 mm
Clr/chord	2.9%	0.5%
Solidity	0.86	1.7
Rotor blades	5	22
Struts/stators	4	54
Flow	40 m ³ /hr	446,000 m ³ /hr
Pressure rise	19 Pa	69,000 Pa



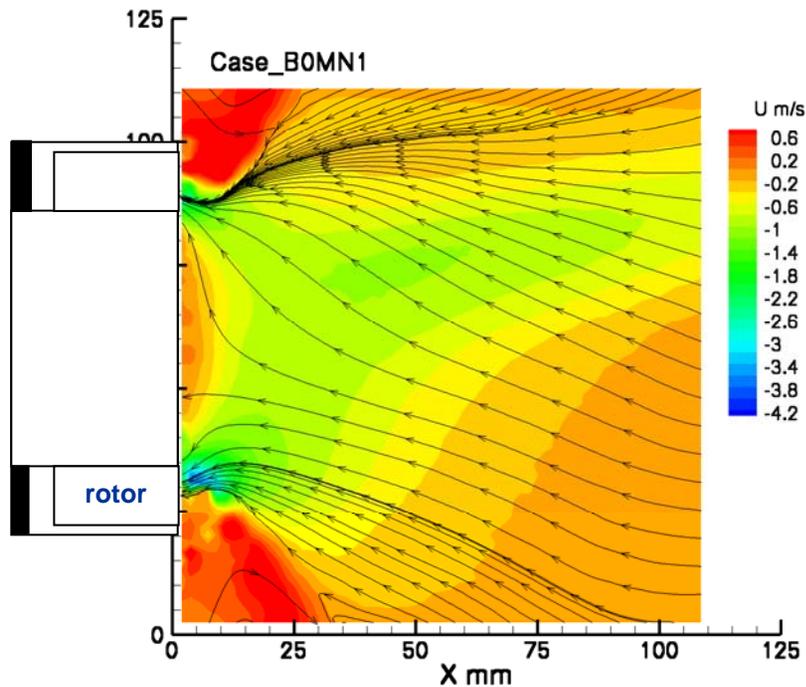
Does it matter?

What happens if the fan is mismatched to the system and operates in mild stall?

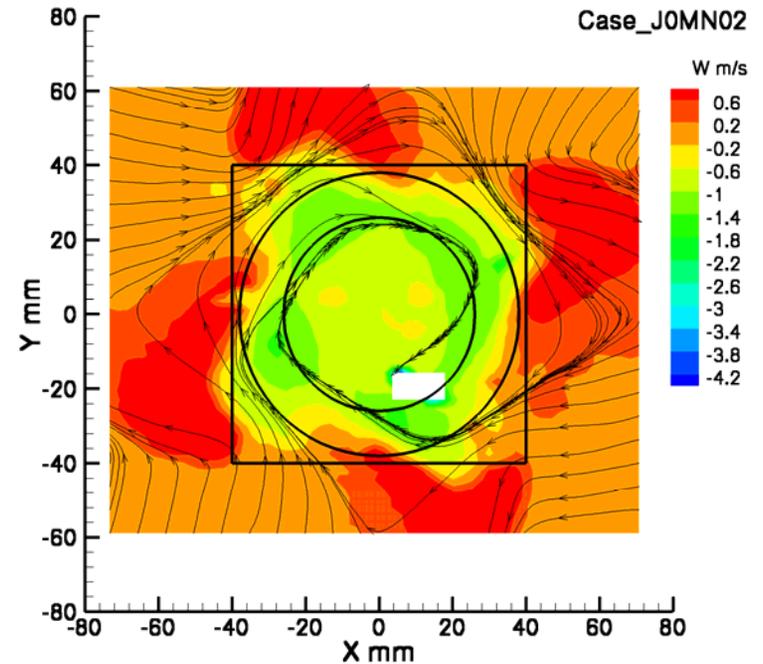




Detailed measurements show the bad airflow



Meridional view, 2D PIV, mild stall.



Fan inlet, 3D PIV, mild stall.

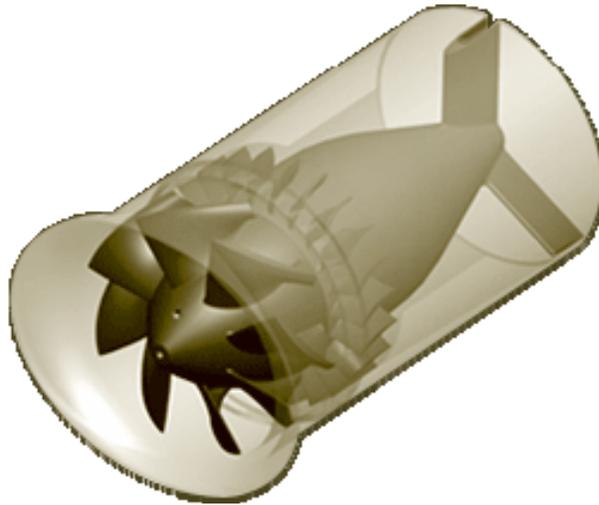
Swirling flow comes OUT of the inlet (red regions in above images) and leaks preferentially at the partial bellmouth cutouts.

Air that the fan is meant to exhaust is recirculated instead.

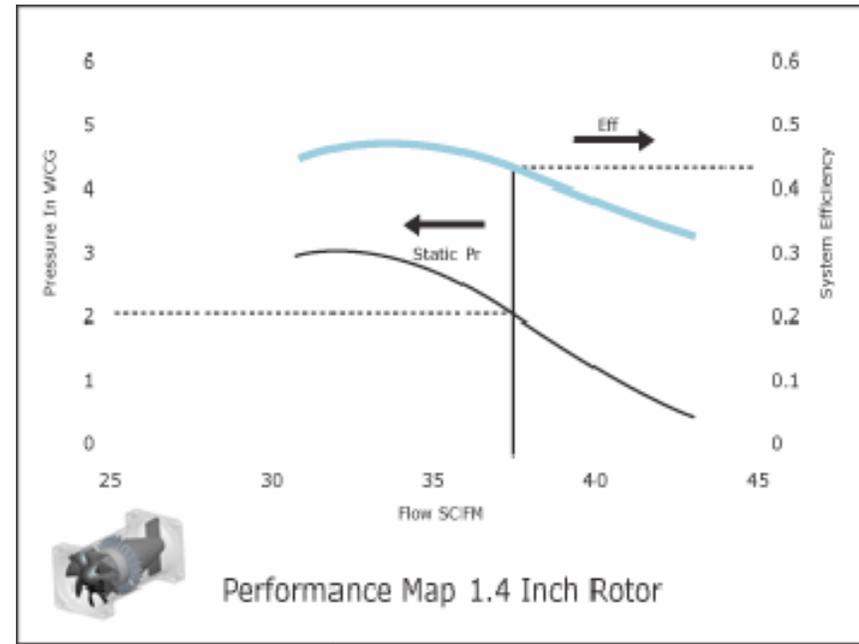


One example of a better aero design

Aircraft engines have long pushed the boundaries of design. Solutions to complex aerodynamic, electrical, mechanical and thermal challenges have been proven in this industry.



37 CFM @ 2 in. H₂O



Xcelaero Corporation

www.xcelaero.com

Former GE Aviation personnel using jet engine design tools.



A 'NASA Fan' Test Case: A possible 'open source' method to advance the technology.



An Example: NASA Rotor 37

In the jet engine R&D world:

The 1980's

- emerging 3D viscous computational codes
- emerging non-intrusive measurement methods

“The ability to *calculate* within blade rows created a *drive* that fueled advancement of methods that could *measure* within blade rows”

The 1990's

- detailed data sets of rotors (R67, R35, R37) and stages
- refined computational methods (turbulence models, leakage models, etc.)

“The existence of high-quality, non-intrusive *data sets* enabled a *drive* for continued refinement of *CFD methods* and *best practices*”

From: Strazisar, Anthony, “The Role of Physical Experiments in Advancing the Design of Aircraft Gas Turbine Compressors,” Pratt & Whitney Aircraft Fellows Seminar, October 2003.

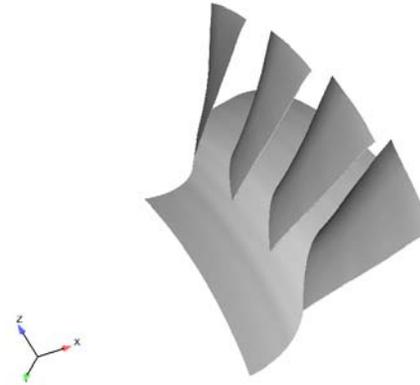


An Example: NASA Rotor 37

In 1994 the American Society of Mechanical Engineers sponsored a blind test case using Rotor 37.

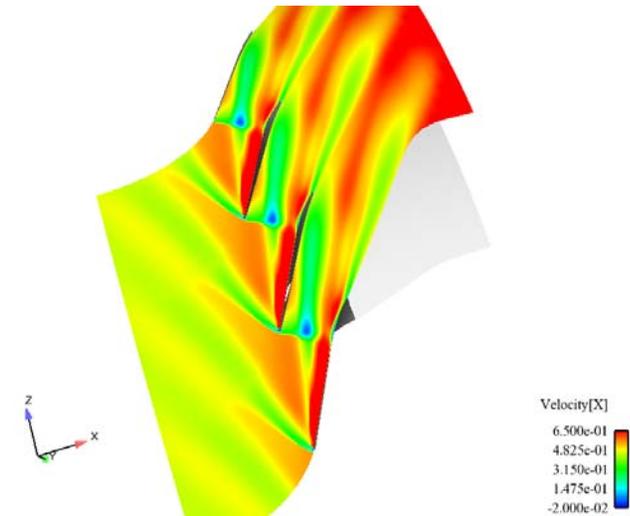
NASA provided:

- Rotor and flow path geometry
- Inlet flow conditions, operating speed



The participants were to use their best computational codes and practices to predict the performance (pressure ratio, efficiency) and some detailed flow features of Rotor 37.

Once the participants delivered their results, NASA provided detailed test performance results and detailed flow field measurements.



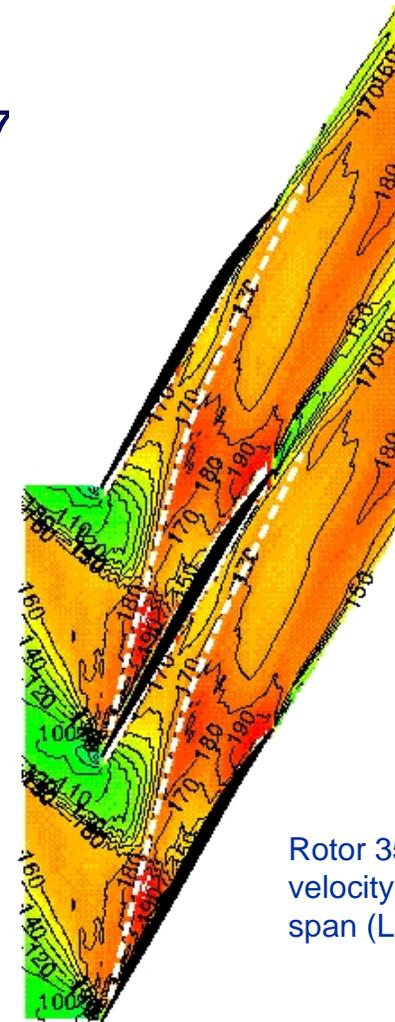


An Example: NASA Rotor 37

The performance estimates from participants varied much more than originally anticipated and, in many cases, were unsatisfactory.

Using the high quality data set for guidance, the organizations developed 'best practices' for analysis, improved numerical methods and turbulence models.

The end result is *validated, trusted* design and analysis tools that can be applied with confidence.



Rotor 35 axial velocity at 92% span (LDV data).

More than a decade later the test cases continue to be used in industry and academia.

- NASA Fan Rotor 67 (Strazisar, et al.)
- NASA Rotor 37 (Suder, et al.)
- NASA Rotor 35 (Van Zante, et al.)



NASA Cooling Fan 1

For a valid test case, we must begin with a good aerodynamic baseline.

The proposed project:

1. For a relevant operating condition (e.g. 24 cfm, 0.08 in. H₂O), design a high performance fan using best practices.
2. Thoroughly document the overall fan performance (flow, pressure rise, efficiency) and acoustics.
3. Measure the detailed flow features which are necessary for code validation (blade wakes, tip clearance flow, etc.). Acquire acoustic data with rotor position reference.

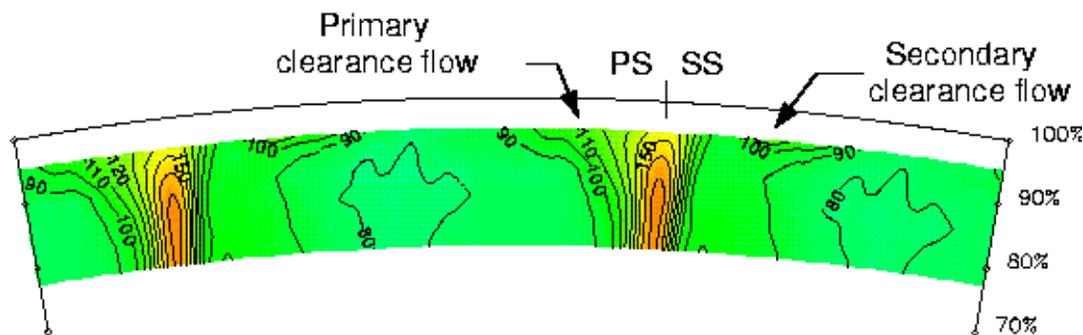
Goal: a fan with acceptable acoustics and 2x the efficiency of a COTS fan.

NASA would own the geometry and test data with the ability to distribute it.

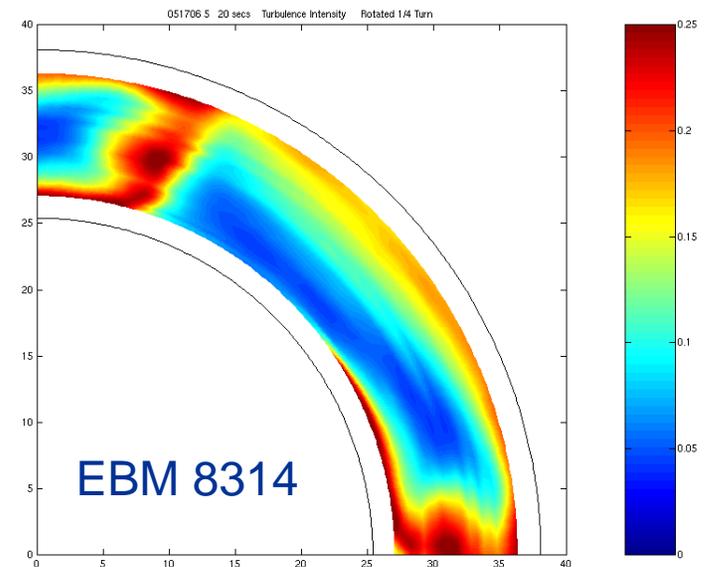


Summary

- Fans are sensitive to their inlet/outlet conditions and proper system installation is key to getting the best performance/acoustics.
- Improvements to small cooling fan performance are possible through better aerodynamic design.
- Proposal: A NASA Fan test case to provide the necessary data for advancing the analysis and design systems for small cooling fans.

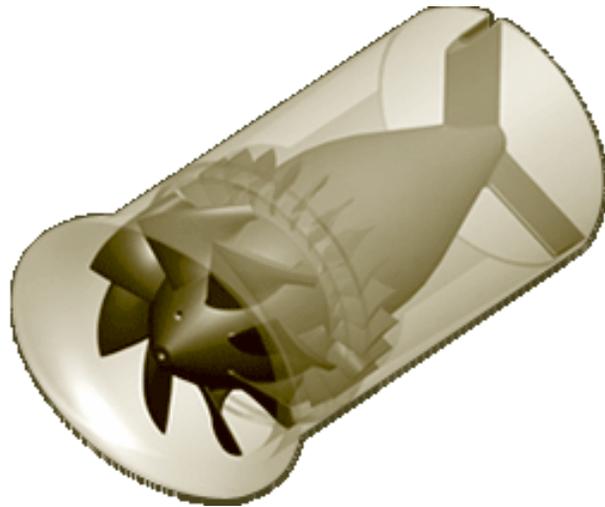


Rotor 35 wakes and tip clearance flow (LDV data).





“Flurry” specs



37 CFM @ 2 in. H₂O

Audio filtered to remove BPF tones
0 - 1 - 1,2 - 1,2,3 - 0



24,000 rpm
400 Hz shaft frequency
3.2 kHz BPF

